DISCHARGE LAMP, METHOD FOR PRODUCING THE SAME AND LAMP UNIT

BACKGROUND OF THE INVENTION

The present invention relates to a discharge lamp and a lamp unit. In particular, a discharge lamp and a lamp unit used as a light source for an image projection apparatus such as a liquid crystal projector and a digital micromirror device (DMD) projector.

In recent years, an image projection apparatus such as a liquid crystal projector and a DMD projector has been widely used as a system for realizing large-scale screen images, and a high-pressure discharge lamp having a high intensity has been commonly and widely used in such an image projection apparatus. In the image projection apparatus, light is required to be concentrated on a very small area of a liquid crystal panel or the like, so that in addition to high intensity, it is also necessary to achieve nearly a point light source. Therefore, among high-pressure discharge lamps, a short arc type ultra high pressure mercury lamp that is nearly a point light and has a high intensity has been noted widely as a promising light source.

Referring to Figs. **21A** to **21C**, a conventional short arc type ultra high pressure mercury lamp **1000** will be described.

Fig. **21A** is a schematic top view of a lamp **1000**. Fig. **21B** is a schematic side view of a lamp **1000**. Fig. **21C** is a cross-sectional view taken along line c-c′ of Fig. **21A**.

The lamp **1000** includes a substantially spherical luminous bulb **110** made of quartz glass, and a pair of sealing portions **120**

and **120′** (seal portions) made of also quartz glass and connected to the luminous bulb **110**. A discharge space **115** is inside the luminous bulb **110**. A mercury **118** in an amount of the enclosed mercury of, for example, 150 to 250mg/cm^3 as a luminous material, a rare gas (e.g., argon with several tens kPa) and a small amount of halogen are enclosed in the discharge space **115**.

A pair of tungsten electrodes (W electrode) **112** and **112′** are opposed with a certain gap in the discharge space **115**, and a coil **114** is wound around the end of the electrode **112** (or **112′**). An electrode axis **116** of the electrode **112** is welded to a molybdenum foil (Mo foil) **124** in the sealing portion **120**, and the W electrode **112** and the Mo foil **124** are electrically connected by a welded portion **117** where the electrode axis **116** and the Mo foil **124** are welded.

The sealing portion **120** includes a glass portion **122** extended from the luminous bulb **110** and the Mo foil **124**. The glass portion **122** and the Mo foil **124** are attached tightly so that the airtightness in the discharge space **115** in the luminous bulb **110** is maintained. The principle on the reason why the luminous bulb **110** can be sealed by the sealing portion **120** will be briefly described below.

Since the thermal expansion coefficient of the quartz glass constituting the glass portion **122** is different from that of the molybdenum constituting the Mo foil **124**, the glass portion **122** and the Mo foil **124** are not integrated. However, by plastically deforming the Mo foil **124**, the gap between the Mo foil **124** and the glass portion **122** can be filled. Thus, the Mo foil **124** and the glass portion **122** are pressed and attached to each other, and

the luminous bulb **110** can be sealed with the sealing portion **120**. In other words, the sealing portion **120** is sealed by attaching the Mo foil **124** and the glass portion **122** tightly for foil-sealing.

The Mo foils **124** of the sealing portions **120** and **120′** have the same size and a rectangular plane shape, and are positioned at the center of the internal portion of the respective sealing portions **120** and **120′** so that the directions x (width directions) perpendicular to the thickness directions **Z** of the foils are in the same direction. In other words, the pair of the sealing portions **120** and **120′** is coupled to the ends of the luminous bulb **110** so that the flat Mo foils **124** are symmetrical with respect to the luminous bulb **110** as the center.

The Mo foil **124** includes an external lead (Mo rod) **130** made of molybdenum on the side opposite to the side on which the welded portion **117** is positioned. The Mo foil **124** and the external lead **130** are welded with each other so that the Mo foil **124** and the external lead **130** are electrically connected at a welded portion **132**. The external lead is electrically connected to a member (not shown) positioned in the periphery of the lamp **1000**.

Next, the operational principle of the lamp **1000** will be described. When a start voltage is applied to the W electrodes **112** and **112′** via the external leads **130** and the Mo foils **124**, discharge of argon (Ar) occurs. Then, this discharge raises the temperature in the discharge space **115** of the luminous bulb **110**, and thus the mercury **118** is heated and evaporated. Thereafter, mercury atoms are excited and become luminous in the arc center between the W electrodes **112** and **112′**. As the pressure of the mercury vapor

of the lamp **1000** is higher, the emission efficiency is higher, so that the higher pressure of the mercury vapor is suitable as a light source for an image projection apparatus. However, in view of the physical strength against pressure of the luminous bulb **110**, the lamp **1000** is used at a mercury vapor pressure of 15 to 25MPa.

As a result of in-depth research, the inventors of the present invention found that the lifetime of the conventional lamp **1000** is shortened by leaks occurring in the sealing portions **120**. More specifically, the sealing portions **120** of the lamp **1000** are sealed by attaching the Mo foils **124** and the glass portions **122** tightly, so that as shown in Fig. **22A** and **22B**, an internal stress **40** occurs in the direction perpendicular to the surface of the foil (the **Z** direction in Figs. **22A** and **22B**) on the Mo foil **124**. Therefore, when the glass portions **122** are deteriorated with use of the lamp **1000** and the strength of the glass portions **112** is reduced, the glass portions **112** can be split by the internal stress **40** on the Mo foils **124** at a certain point. When the glass portions are split, air is let into the sealing portions **120** so that the Mo foils **124** are oxidized. Thus, the conductivity of the Mo foils **124** is lost, so that the lamp **1000** stops its operation.

Furthermore, in the welded portions **132** in the sealing portions **120**, the Mo foils **124** and the external leads **130** are substantially in point contact with each other, so that the contact area therebetween is small. Therefore, a local increase in the temperature is often caused by current flowing from the external leads **130** to the Mo foils **124**. Molybdenum constituting the Mo

foils **124** has the nature that it is oxidized at 350°C or more, so that this local increase in the temperature causes a large problem when the Mo foils **124** are used. There may be an approach of suppressing the local increase in the temperature of the welded portion **132** by increasing the size of the Mo foils **124** to increase the heat capacity. However, it is difficult to adopt this approach in the context that there is a great demand for compactness of the lamp size with a trend of compactness of image projection apparatuses. Furthermore, to achieve high intensity, there is a tendency of reducing the electrode distance **L** between the W electrodes **112** and **112′** (to achieve a short arc) to allow a large amount of current to flow. Therefore, the problem of the local increase in the temperature of the welded portions **132** may become more serious. Furthermore, even if the oxidation of the Mo foils **124** does not occur, the local increase in the temperature of the welded portions **132** may generate a starting point of cracks in the glass in the periphery of the welded portions **132**. Therefore, the temperature increase is problematic also in view of a cause of leaks of the sealing portions **120**.

SUMMARY OF THE INVENTION

Therefore, with the foregoing in mind, it is a main object of the present invention to provide a discharge lamp having a long lifetime in which the sealing structure of the sealing portions can be maintained for a long period. It is another object of the present invention to provide a discharge lamp having a long lifetime in which a local increase in the temperature is prevented.

A discharge lamp of the present invention includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of metal foils electrically connected to the pair of electrodes, respectively; wherein at least one of the pair of metal foils has a twist structure. This structure can solve the above problems.

It is preferable that the metal foil having a twist structure has a 90° twisted portion.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of metal foils electrically connected to the pair of electrodes, respectively; wherein each of the pair of metal foils has an external lead on a side opposite to a side electrically connected to a corresponding electrode of the pair of electrodes, at least one of the pair of metal foils has a corrugated structure in which the metal foils are corrugated along a longitudinal direction of the metal foils, and the metal foil having the corrugated structure has at least one wave portion in an area between an end of the electrode and an end of the external lead of the metal foil.

It is preferable that at least one wave crest of the wave portion is provided in an area on the luminous bulb side from a midpoint of the metal foil in the longitudinal direction of the metal foil (including the midpoint).

It is preferable that a plurality of wave crests of the wave

portion are provided in an area between the end of the electrode and the end of the external lead of the metal foil.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of metal foils electrically connected to the pair of electrodes, respectively; wherein a first direction perpendicular to a thickness direction of one metal foil of the pair of metal foils is different from a second direction perpendicular to a thickness direction of the other metal foil.

In one embodiment of the present invention, the first direction and the second direction are dislocated by 1° to 90°.

In another embodiment of the present invention, at least one of the pair of metal foils has a twist structure.

In still another embodiment of the present invention, at least one of the pair of metal foils has a corrugated structure.

In yet another embodiment of the present invention, the metal foil having a corrugated structure has at least one bend portion for dispersing directions of internal stresses of the metal foil in the sealing portion.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of metal foils electrically connected to the pair of electrodes, respectively; wherein each of the pair of metal foils has an external

lead on a side opposite to a side electrically connected to a corresponding electrode of the pair of electrodes, and in at least one of the pair of metal foils, an area of the metal foil projected from the luminous bulb side to the external lead side is larger than an area of an end face of the metal foil.

In one embodiment of the present invention, each of the pair of metal foils is tightly attached to a glass portion extending from the luminous bulb, and each of the pair of metal foils is a molybdenum foil.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of molybdenum foils electrically connected to the pair of electrodes, respectively; wherein each of the pair of molybdenum foils has an external lead made of molybdenum on a side opposite to a side electrically connected to a corresponding electrode of the pair of electrodes, and at least one of the pair of molybdenum foils is integrally formed with the external lead.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of molybdenum foils electrically connected to the pair of electrodes, respectively; wherein each of the pair of molybdenum foils has an external lead made of molybdenum on a side opposite to a side electrically connected to a corresponding electrode of the pair

of electrodes, and at least one of the pair of molybdenum foils is plane-welded to the external lead in which a portion to be connected to the molybdenum foil is plane-shaped.

According to another aspect of the present invention, a discharge lamp includes a luminous bulb in which a luminous material is enclosed and a pair of electrodes are opposed in the luminous bulb; and a pair of sealing portions for sealing a pair of molybdenum foils electrically connected to the pair of electrodes, respectively; wherein at least one of the pair of molybdenum foils has a molybdenum rod extending from the molybdenum foil to the luminous bulb, and the molybdenum rod is connected to either one of the pair of electrodes by welding.

In one embodiment of the present invention, each of the pair of sealing portion has a shrink seal structure.

In another embodiment of the present invention, the luminous material comprises at least mercury.

According to another aspect of the present invention, a lamp unit of the present invention includes the discharge lamp of the present invention and a reflecting mirror for reflecting light emitted from the discharge lamp.

According to another aspect of the present invention, a method for producing a discharge lamp comprising the steps of: (a) preparing a pipe for a discharge lamp including a luminous bulb portion and a side tube portion extending from the luminous bulb portion; and an electrode assembly including a metal foil, an electrode connected to the metal foil, and an external lead connected to the metal foil on a side opposite to a side connected to the electrode; (b)

inserting the electrode assembly into the side tube portion so that an end of the electrode is positioned inside the luminous bulb portion; (c) attaching the side tube portion to the metal foil by reducing a pressure in the pipe for a discharge lamp and heating and softening the side tube portion after the step (b); and (d) forming a twist structure or a corrugated structure in the metal foil by applying an external force to the metal foil after the step (b).

In one embodiment of the present invention, after the side tube portion and the metal foil are attached in the step (c), the step (d) is performed in a state where a part of the attached side tube portion is heated and softened.

In another embodiment of the present invention, the step (d) is performed in a state where a part of the side tube portion and a part of the metal foil are attached by the step (c), and thereafter the step (c) is performed again.

In still another embodiment of the present invention, in the step (a), the electrode assembly is prepared in which the metal foil is a molybdenum foil, and a molybdenum tape for fixing the electrode assembly in the side tube portion is provided in a part of the external lead. In the step (b), the molybdenum tape is engaged in an inner surface of the side tube portion so that the end of the electrode is positioned in the luminous bulb portion. In the step (c), the side tube portion and the metal foil are attached while rotating the pipe for a discharge lamp. In the step (d), the twist structure or the corrugated structure is formed in the metal foil by making a difference in a rotation speed of the pipe

for a discharge lamp between the electrode side and the external lead side in the metal foil, or by contracting the side tube portion so that a portion on the electrode side and a portion on the external lead side in the metal foil are brought relatively close to each other.

Hereinafter, the functions of the present invention will be described.

The discharge lamp of the present invention has a twist structure in at least one of a pair of metal foils, and therefore the internal stresses (internal stresses of the metal foils) occurring perpendicularly to the surface of the metal foils in the sealing portions are not directed to one and the same direction. Therefore, the directions of the internal stresses of the metal foils can be dispersed. When the directions of the internal stresses of the metal foils can be dispersed, the synthetic stress that causes the metal foils to split the sealing portions (the synthetic stress destroying the sealing structure) can be reduced. Thus, the sealing structure of the sealing portions can be maintained for a long time, compared with the prior art. As a result, the lifetime of the discharge lamp can be prolonged. When the metal foils are twisted 90°, the synthetic stress that causes the metal foils to split the sealing portions can be minimized.

Also when at least one of the pair of metal foils has a corrugated structure, the internal stresses in the sealing portions can be dispersed. As a result, the lifetime of the discharge lamp can be longer than that of the prior art. When a bend portion for dispersing the directions of the internal stresses of the metal

foils in the sealing portions is formed in at least one of the metal foils, the synthetic stress that causes the metal foils to split the sealing portions can be reduced. In the case of this structure, when a wave portion is provided in an area between the edge of the electrode and the edge of the external lead of the metal foil, the internal stresses in the sealing portion can be dispersed without reducing the connection strength between the electrode and the metal foil and the connection strength between the external lead and the metal foil. Furthermore, when a wave crest of the wave portion is provided in an area on the luminous bulb side from the midpoint of the metal foil, the sealing structure in the sealing portion can be maintained for a long time more effectively. In addition, a plurality of wave crests are provided in the wave portion.

When a first direction perpendicular to the thickness direction of one of the pair metal foils is different from a second direction perpendicular to the thickness direction of the other metal foil, the sum of the internal stresses of the first directions and the second directions can be lower than that of the prior art. Therefore, the synthetic stress that causes the metal foils to split the sealing portions can be weakened, so that the lifetime of the discharge lamp can be prolonged. It is preferable that the first direction is dislocated by 1 to 90° from the second direction. When the first direction is dislocated by 90° from the second direction, the sum of the internal stresses in the first direction and the second direction can be minimized. In addition, in order to disperse the internal stresses of the sealing portion,

at least one of the pair of metal foils has the twist structure or the corrugated structure.

When the metal foil is formed in such a manner that the area of the metal foil projected from the luminous bulb side to the external lead side is larger than the area of the end face of the metal foil, the surface of the metal foil can receive energy moving from the luminous bulb to the external leads in a manner similar to in an optical fiber. For this reason, the energy by the optical fiber-like effect that reaches the junction portions between the metal foils and the external leads can be reduced. As a result, the temperature increase in the junction portions between the metal foils and the external leads can be reduced.

Each of the pair of metal foils can be designed to be pressed by the glass portions extended from the luminous bulb, and a molybdenum foil can be used as each of the pair of metal foils. In order to make it difficult for the sealing portions to split, a metal foil having a sharp side is used preferably.

When the external leads are formed integrally with the molybdenum foils, heat generation by current generated in the welded portions of the external leads and the molybdenum foils in the prior art can be suppressed. Thus, compared with the prior art, it is possible to suppress the generation of the starting point of cracks in the sealing portions (glass portions) in the periphery of the welded portions by the local temperature increase in the welded portions, so that the lifetime of the discharge lamp can be prolonged.

Furthermore, when the external leads are formed integrally

with the molybdenum foils, this structure makes it difficult to form the gap between the junction portions between the molybdenum foils and the external leads and the sealing portions (glass portions). As a result, the strength of the sealing portions can be improved. When the portion of the external lead that is connected to the molybdenum foils is planed, heat generation due to current occurring in the welded portion can be suppressed, and it is difficult to form the gap between the junction portions and the sealing portions (glass portions), compared with the prior art.

Furthermore, when a molybdenum rod extended from the molybdenum foil to the luminous bulb is connected to one of a pair of electrodes by welding, the junction portion between the molybdenum foil and the electrode can have a smooth shape so that cracks are unlikely to remain in the sealing portion (glass portion) in the periphery of the junction portions. As a result, the strength of the discharge lamp can be improved.

It is preferable that each of the pair of sealing portions has a shrink sealing structure to improve the resistance to pressure. Examples of the discharge lamp of the present invention include a mercury lamp comprising at least mercury as a luminous material (including ultra high pressure mercury lamp, high pressure mercury lamp and low pressure mercury lamp). Alternatively, a lamp unit including the discharge lamp of the present invention in combination with a reflecting mirror can be formed. Furthermore, according to the method for producing a discharge lamp of the present invention, a discharge lamp including a metal foil having the twist structure or the corrugated structure can be produced relatively easily.

According to one embodiment of the discharge lamp of the present invention, since at least one of a pair of metal foils has a twist structure, the sealing structure in the sealing portion can be maintained for a long time, so that the lifetime of the discharge lamp can be prolonged.

According to another embodiment of the discharge lamp of the present invention, since at least one of a pair of metal foils has a corrugated structure, the sealing structure in the sealing portion can be maintained for a long time, so that the lifetime of the discharge lamp can be prolonged.

According to still another embodiment of the discharge lamp of the present invention, since a first direction perpendicular to the thickness direction of one metal foil is different from a second direction perpendicular to the thickness direction of the other metal foil, the sealing structure in the sealing portion can be maintained for a long time, so that the lifetime of the discharge lamp can be prolonged.

According to yet another embodiment of the discharge lamp of the present invention, since the area of the metal foil projected from the luminous bulb side to the external lead side is larger than the area of the end face of the metal foil, the temperature increase generated by energy by the optical fiber-like effect can be suppressed, and the reliability of the discharge lamp can be improved.

According to another embodiment of the discharge lamp of the present invention, at least one of a pair of molybdenum foils is formed integrally with the external lead. Therefore, the local

temperature increase in the sealing portion can be prevented, and the lifetime of the discharge lamp can be prolonged.

According to still another embodiment of the discharge lamp of the present invention, the portion connected to the molybdenum foil is plane welded with the external leads having a plane shape. Therefore, the local temperature increase in the sealing portion can be prevented, and the lifetime of the discharge lamp can be prolonged.

According to still another embodiment of the discharge lamp of the present invention, since the molybdenum foil has a molybdenum rod extending from the molybdenum foil to the luminous bulb, and the molybdenum rod is welded to either one of the pair of electrodes. Therefore, the strength of the sealing portion can be prevented from deteriorating, so that the lifetime of the discharge lamp can be prolonged.

According to the method for producing a discharge lamp of the present invention, a discharge lamp including a sealing portion having the twist structure or the corrugated structure can be produced relatively easily.

This and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. **1A** is a schematic top view showing a structure of a discharge lamp **100** of Embodiment **1**.

Fig. **1B** is a schematic side view showing a structure of a discharge lamp **100** of Embodiment **1.**

Fig. **1C** is a cross-sectional view taken along line c-c′ of Fig. **1A.**

Fig. **1D** is a schematic enlarged view showing the shape of an end face of a metal foil **24.**

Fig. **2** is a cross-sectional enlarged view showing a twist structure of the metal foil.

Figs. **3A** to **3C** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **100** of Embodiment **1.**

Fig. **4** is a cross-sectional view for illustrating a method for producing the discharge lamp **100** of Embodiment **1.**

Figs. **5A** to **5D** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **100** of Embodiment **1.**

Figs. **6A** to **6D** are cross-sectional views of a process sequence for illustrating another method for producing the discharge lamp **100** of Embodiment **1.**

Fig. **7A** is a schematic top view showing a structure of a discharge lamp **200** of Embodiment **2.**

Fig. **7B** is a schematic side view showing a structure of a discharge lamp **200** of Embodiment **2.**

Fig. **7C** is a cross-sectional view taken along line c-c′ of Fig. **7A.**

Fig. **8** is a cross-sectional enlarged view showing a corrugated structure of the metal foil.

Figs. **9A** to **9C** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **200** of Embodiment **2**.

Figs. **10A** to **10D** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **200** of Embodiment **2**.

Figs. **11A** to **11D** are cross-sectional views of a process sequence for illustrating another method for producing the discharge lamp **200** of Embodiment **2**.

Fig. **12A** is a schematic top view showing a structure of a discharge lamp **300** of Embodiment **2**.

Fig. **12B** is a cross-sectional view taken along line b-b′ of Fig.**12 A**.

Fig. **13** is a cross-sectional view of a comparative example of the discharge lamp **200** of Embodiment **2**.

Fig. **14A** is a schematic top view showing a structure of a discharge lamp **400** of Embodiment **3**.

Fig. **14B** is a schematic side view showing a structure of the discharge lamp **400**.

Fig. **14C** is a cross-sectional view taken along line c-c′ of Fig. **14A**.

Fig. **14D** is a cross-sectional view taken along line d-d′ of Fig. **14A**.

Figs. **15A** to **15C** are views for illustrating Embodiment **3**.

Fig. **16A** is a schematic top view showing a structure of a discharge lamp **500** of Embodiment **4**.

Fig. **16B** is a cross-sectional view taken along line b-b′

of Fig. **16A**.

Fig. **17** is a schematic top view showing a structure of a discharge lamp **600** of Embodiment **5**.

Fig. **18** is a schematic top view showing a structure of a discharge lamp **700** of Embodiment **5**.

Fig. **19** is a schematic top view showing a structure of a discharge lamp **800** of Embodiment **6**.

Fig. **20** is a schematic top view showing a structure of a discharge lamp **900** of Embodiment **7**.

Fig. **21A** is a schematic top view showing a structure of a conventional discharge lamp **1000**.

Fig. **21B** is a schematic side view showing a structure of a discharge lamp **1000**.

Fig. **21C** is a cross-sectional view taken along line c-c' of Fig. **21A**.

Figs. **22A** and **22B** are views for illustrating the problems of the conventional discharge lamp **1000**.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, embodiment of the present invention will be described with reference to the accompanying drawings. In the following drawings, the elements having substantially the same functions bear the same reference numeral.

<u>Embodiment 1</u>

A discharge lamp **100** of Embodiment **1** of the present invention will be described with reference to Figs. **1** to **4**.

First, Figs. **1A** to **1D** are referred to. Fig. **1A** is a schematic

top view showing a structure of a discharge lamp **100** of Embodiment 1. Fig. **1B** is a schematic side view showing a structure of the discharge lamp **100**. Fig. **1C** is a cross-sectional view taken along line c-c′ of Fig. **1A**. Fig. **1D** is a schematic enlarged view showing the shape of an end face of a metal foil **24**. The arrows **X**, **Y** and **Z** in Figs. **1A** to **1D** show the coordinate axes.

The discharge lamp **100** of Embodiment **1** includes a luminous bulb (bulb) **10**, and a pair of sealing portions **20** and **20′** connected to the luminous bulb **10**.

A discharge space **15** in which a luminous material **18** is enclosed is provided inside the luminous bulb **10**. A pair of electrodes **12** and **12′** are opposed to each other in the discharge space **15**. The luminous bulb **10** is made of quartz glass and is substantially spherical. The outer diameter of the luminous bulb **10** is, for example, about 5mm to 20mm. The glass thickness of the luminous bulb is, for example, about 1mm to 5mm. The volume of the discharge space **15** in the luminous bulb **10** is, for example, about 0.01 to 1cc. In this embodiment, the luminous bulb **10** having an outer diameter of about 13mm, a glass thickness of about 3mm, a volume of the discharge space **15** of about 0.3cc is used. As the luminous material **18**, mercury is used. For example, about 150 to 200mg /cm^3 of mercury, a rare gas (e.g., argon) with 5 to 20kPa, and a small amount of halogen are enclosed in the discharge space **15**. In Figs. **1A** and **1B**, mercury **18** attached to the inner wall of the luminous bulb **10** is schematically shown.

The pair of electrodes **12** and **12′** in the discharge space **15** are arranged with a gap (arc length) of, for example, about

1 to 5mm. As the electrodes **12** and **12'**, for example, tungsten electrodes (W electrodes) are used. In this embodiment, the W electrodes **12** and **12'** are arranged with a gap of about 1.5mm. A coil **14** is wounded around the end of each of the electrodes **12** and **12'**. The coil **14** has a function to lower the temperature of the electrode end. An electrode axis (W rod) **16** of the electrode 12 is electrically connected to the metal foil **24** in the sealing portion **20**. Similarly, an electrode axis **16** of the electrode **12'** is electrically connected to the metal foil **24'** in the sealing portion **20'**.

The sealing portion **20** includes a metal foil **24** electrically connected to the electrode 12 and a glass portion **22** extended from the luminous bulb **10**. The airtightness in the discharge space **15** in the luminous bulb **10** is maintained by the foil-sealing between the metal foil **24** and the glass portion **22** In other words, the sealing portion **20** is a portion foil-sealed by the metal foil **24** and the glass portion **22**. The metal foil **24** is a molybdenum foil (Mo foil), for example, and has a rectangular shape, for example. The glass portion **22** is made of quartz glass, for example.

As shown in Fig. **1D**, the thickness **d** of the metal foil **24** is about 20 μm to 30 μm. The width **w** of the metal foil **24** is for example, about 1.5mm to 2.5mm. The ratio of the thickness **d** to the width **w** is about 1: 100. In this embodiment, as shown in Fig. **1D**, the side of the metal foil **24** is sharp. This design is adopted to prevent the internal stress occurring perpendicularly to the side of the metal foil **24** from being directed to a direction x perpendicular to the direction **z** of the thickness of the foil as

much as possible, so that the sealing portion **20** is prevented from splitting as much as possible. This design of the sealing portion **20** applies to the sealing portion **20′**, so that further description is omitted.

The metal foil **24** of at least one of the pair of sealing portions (the sealing portion **20** in the drawings) has a twist structure, and the metal foil **24** has a twisted portion (twist portion) **26** with respect to the other portion (e.g., the portion on the luminous bulb **10** side of the metal foil **24**). Fig. **2** is an enlarge view showing the twist structure of the metal foil **24**.

As shown in Fig. **2**, with the metal foil **24** of the twist structure, the direction of the internal stresses **40** occurring perpendicularly to an upper surface **24a** and a lower surface **24b** of the metal foil **24** are not uniform to the thickness direction **Z** of the foil. Accordingly, the directions of the internal stresses **40** of the metal foil **24** can be dispersed to directions other than the thickness direction **Z** of the foil, so that the synthetic stress that causes the metal foil **24** to split the sealing portion **20** (glass portion **22**), that is, the synthetic stress of the internal stresses **40** in the thickness direction **Z** of the foil, can be reduced. As a result, the sealing structure of the sealing portion **20** can be maintained for a long time, and the lifetime of the discharge lamp **100** can be prolonged.

In this embodiment, the angle of the twisted portion **26** (twist angle) with respect to the portion on the luminous bulb **10** side of the metal foil **24** is about 180 degrees. However, the twist angle is not limited to about 180 degree. In order to reduce more

significantly the synthetic stress that causes the metal foil **24** to split the sealing portion **20** (glass portion **22**), that is, the synthetic stress of the internal stresses **40** in the thickness direction of the foil, it is preferable that the twist angle is at least 30 degrees. In order to reduce the synthetic stress splitting the sealing portion **20** by about 15%, it is preferable that the twist angle is, for example, about 45 degrees.

When the twist angle is 90°, the synthetic stress splitting the sealing portion **20** is smallest, so that it is more preferable that the twist angle of at least one twist portion **26** is 90°. The twist angle of the twist portion **26** can be 90 degrees or more, and can be 180 degrees as in this embodiment. When the twist angle is about 180 degrees, each the upper surface **24a** and the lower surface **24b** of the metal foil **24** draw a locus of a semicircle, when viewed from the luminous bulb **10** side, as shown by a dotted line in Fig. **1C**. The twist portion **26** is formed in at least one portion in the metal foil **24**. In order to reduce the synthetic stress splitting the sealing portion **20** to a larger extent, it is preferable to form a plurality of twist portions. Furthermore, it is preferable that the twist angle is not less than 36 degrees and the whole metal foil **24** has a twist structure (spiral structure).

In this embodiment, one of the pair of sealing portions **20** has the twist structure, but the other sealing portion **20'** can have the twist structure. It is more preferable that both of the sealing portions have the twist structure, because the sealing structures of both of the sealing portions **20** and **20'** can be maintained for a long time.

The outer diameter of each of the sealing portions **20** and **20′** is, for example, about 4mm to 8mm, and the length in the longitudinal direction (the **Y** direction in Figs. **1A**) thereof is, for example, about 15mm to 30mm. It is preferable that the sealing portions **20** and **20′** have shrink sealing structures to increase the resistance to sealing pressure. However, in the case where the resistance to sealing pressure of about 4 to 5MPa of the internal stress is required, a pinch sealing structure can be used.

The metal foil **24** of the sealing portion **20** (or **20′**) is joined with the electrode **12** by welding, and the metal foil **24** includes an external lead **30** on the side opposite to the side where the electrode **12** is joined. The external lead **30** is made of, for example, molybdenum.

Next, referring to Figs. **3A** to **3C** and **4**, an illustrative method for producing the discharge lamp **100** will be described. Figs. **3A** to **3C** are cross-sectional views showing a process sequence in the method for producing the discharge lamp **100**.

As shown in Fig. **3A**, the metal foil (Mo foil) **24** having the electrode **12** and the external lead **30** is inserted in a glass pipe for discharge lamps having a portion for the luminous bulb **10** (luminous bulb portion) and a portion for the glass portion **22** (glass tube or side tube portion **22**) (electrode insertion process).

Then, as shown in Fig. **3B**, the pressure in the glass pipe is reduced (e.g., one atmospheric pressure or less), and the glass tube (side tube portion) **22** is heated and softened, so that the glass tube **22** and the metal foil **24** are attached so that the sealing portion **20** is formed (sealing portion formation process).

Then, as shown in Fig. **3C**, while the glass tube (glass portion) **22** is still soft, the sealing portion **20** is twisted, so that the metal foil **24** is also twisted together with the glass tube (glass portion) **22** because the metal foil **24** is soft. Thus, the twist portion **26** can be formed (twist portion formation process). In this manner, the discharge lamp **100** provided with the metal foil **24** having the twist structure can be produced.

The electrode insertion process to the twist portion formation process can be performed, for example, in the manner shown in Fig. **4**.

First, a glass pipe is disposed in a vertical direction (the **Y** direction in Fig. **4**), and then the upper portion and the lower portion of the glass pipe are supported with a chuck (not shown) so that the glass pipe can be rotated in the direction of the arrows **41** and **42**. Next, the metal foil **24** having the electrode **12** and the external lead **30** is inserted in a glass pipe, and then the glass pipe is put to be ready for pressure reduction. Then, the pressure in the glass pipe is reduced (e.g., 20kPa), and the glass pipe is rotated in the directions shown by the arrows **41** and **42**, and then a part of the glass tube **22** is heated and softened by, for example, a burner **50**.

The glass tube **22** and the metal foil **24** are attached by the difference in the pressure between the inside and the outside of the glass tube **22**. Then, the rotation speed is made different between the upper portion and the lower portion of the glass pipe. Thus, a part of the glass tube **22** heated and softened by the burner **50** is twisted, and thus the twist portion **26** can be formed in this

portion. In order to make the rotation speed different between the upper portion and the lower portion of the glass pipe, for example, the rotation of the upper portion of the glass pipe as shown by the arrow **41** is not changed, and the rotation of the lower portion of the glass pipe as shown by the arrow **42** is stopped.

More specifically, the method shown in Fig. **4** can be performed in the manner shown in Figs. **5A** to **5D**. Figs. **5A** to **5D** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **100** of this embodiment.

First, as shown in Fig. **5A**, a pipe for a discharge lamp including a luminous bulb portion **10** and a side tube portion **22** and an electrode assembly including a metal foil (Mo foil) **24**, an electrode 12 connected to the metal foil, and an external lead **30** connected to the metal foil. A supporting member **31** for fixing the electrode assembly in the inner surface of the side tube portion **22** is provided in one end of the external lead **30** of the electrode assembly. For example, a molybdenum tape (Mo tape) made of molybdenum can be used as the supporting member **31**. As the metal foil **24** of the electrode assembly, a substantially straight foil can be used. In other words, in this embodiment, the metal foil **24** is not twisted at first.

It is preferable that the glass pipe for a discharge lamp prepared in this embodiment is made of quartz comprising a low level of impurities to prevent blackening and devitrification in the luminous bulb effectively. In this embodiment, a high purity quartz glass comprising a very low level, for example, several ppm or less, preferably, 1ppm or less each of alkali impurities

(Na, K, Li). However, the present invention is not limited thereto, and it is possible to prepare and use a glass pipe for a discharge lamp made of quartz glass comprising a not so low level of alkali impurities.

Next, as shown in Fig. **5B**, the prepared glass pipe is disposed in a vertical direction with a chuck (not shown), and then the electrode assembly is inserted in the side tube portion **22** so that the end of the electrode 12 is in a predetermined position in the luminous bulb portion **10** with the metal foil **24** in a straight state. When the end of the electrode **12** is positioned in the predetermined position, the electrode assembly is fixed in the side tube portion **22** with the Mo tape **31**. Thereafter, the entire glass pipe is purged with an inert gas at one atmospheric pressure or less (e.g., Ar gas at about 50Torr).

Next, as shown in Fig. **5C**, the side tube portion **22** is heated and melted while rotating the glass pipe, so that the entire metal foil **24** of the electrode assembly is attached to the side tube portion **22** for sealing so as to form the sealing portion **20**. Thereafter, as shown in Fig. **5D**, first, the sealing portion **20** (glass portion **22**) corresponding to a site to be twisted of the metal foil **24** is heated and melted. Then, the rotation speed in one end of the glass pipe is made different from that in the other end, so that the twist portion **26** is formed in the metal foil **24**. Thus, the metal foil **24** having the twist structure can be produced relatively easily. Therefore, the discharge lamp **100** of this embodiment can be obtained by a known technique.

The metal foil **24** having the twist structure can be produced

in the manner shown in Figs. **6A** to **6D**.

First, in the same manner as shown in Figs. **5A** and **5B**, as shown in Figs. **6A** and **6B**, the electrode assembly is inserted in the side tube portion **22** of the prepared glass pipe, and then the glass pipe is purged with an inert gas with one atmospheric pressure or less.

Next, as shown in Fig. **6C**, the glass pipe is heated and melted from around a boundary portion between the luminous bulb portion **10** and the side tube portion **22** toward the end of the side tube portion **22** (upper portion) to shrink the side tube portion **22** so that a part of the metal foil **24** of the electrode assembly and a part of the side tube portion (glass portion) **22** are attached for sealing. Then, as shown in Fig. **6D**, when heating reaches the site to be twisted of the metal foil **24**, the rotation speed in one end of the glass pipe is made different from that in the other end, so that the twist portion **26** can formed in the metal foil **24**. Thereafter, the rotation speeds are returned to be the same, so that the metal foil **24** is attached to the side tube portion **22** for sealing in a straight state again. In this manner as well, the metal foil **24** having the twist structure can be produced.

In the example shown in Figs. **6A** to **6D**, heating and melting is performed from the boundary portion between the luminous bulb portion **10** and the side tube portion **22** toward the end of the side tube portion **22**. However, heating and melting can be performed from the end of the side tube portion **22** toward the boundary portion between the luminous bulb portion **10** and the side tube portion **22**. In this case as well, when heating reaches the site to be

twisted of the metal foil **24**, the twist portion **26** is formed in the metal foil **24** by making the rotation speed in one end of the glass pipe different from that in the other end.

According to the discharge lamp **100** of this embodiment, the metal foil **24** in the sealing portion **20** has the twist structure, so that the internal stresses **40** in the sealing portion **20** can be dispersed. Therefore, compared with the prior art, the sealing structure of the sealing portion **20** can be maintained for a long time and the lifetime of the lamp can be prolonged.

Embodiment 2

A discharge lamp **200** of Embodiment **2** of the present invention will be described with reference to Figs. **7** to **9**. The discharge lamp **200** of this embodiment is different from the discharge lamp **100** of Embodiment **1** provided with the metal foil **24** having the twist structure, in that the metal foil **24** has a corrugated structure in Embodiment **2**. For simplification of description of this embodiment and the following embodiments, the points different from Embodiment **1** will be described, and description of the same points are either omitted or simplified.

Fig. **7A** is a schematic top view of the discharge lamp **200** of this embodiment. Fig. **7B** is a schematic side view of the discharge lamp **200**. Fig. **7C** is a cross-sectional view taken along line c-c′ of Fig. **7A**.

The discharge lamp **200** of Embodiment **2** includes a luminous bulb **10**, and a pair of sealing portions **20** and **20′** connected to the luminous bulb **10**. The metal foil **24** of at least one of the

pair of sealing portions **20** and **20′** (the sealing portion **20** in Figs. **7A** to **7C**) has a corrugated structure. The metal foil **24** having a corrugated structure has at least one wave portion (bend portion) **28** for dispersing the internal stresses **40** in the metal foil **24**. When the wave portion (bend portion) **28** is formed in the metal foil **24**, as shown by a dotted line in Fig. **7C**, the upper surface **24a** and the lower surface **24b** of the metal foil **24** in the portion in which the wave portion **28** is formed appear beyond the upper and the lower edges of the end face of the metal foil **24**, when viewed from the luminous bulb **10** side. Fig. **8** is an enlarged view of the corrugated structure of the metal foil **24**.

As shown in Fig. **8**, when the metal foil **24** has the corrugated structure in which the metal foil **24** is corrugated in the longitudinal direction (**Y** direction), the internal stresses **40** occurring perpendicularly to the upper surface **24a** and the lower surface **24b** of the metal foil **24** are not directed uniformly to the thickness direction **Z** of the foil. Thus, the internal stresses **40** of the metal foil **24** can be dispersed, so that the synthetic stress that causes the metal foil **24** to split the sealing portion **20** (glass portion **22**), that is, the synthetic stress of the internal stress **40** in the thickness direction **Z** of the foil, can be reduced. As a result, the sealing structure of the sealing portion **20** can be maintained, so that the lifetime of the discharge lamp **100** can be prolonged.

It is preferable that the wave portion **28** is formed in an area **24u** that is from the end **12e** of the electrode **12** to the end **30e** of the external lead **30** of the metal foil **24**. The reason is

as follows. Since the electrode **12** and the external lead **30** are connected to the metal foil **24** by welding, the connection strength between the electrode **12** and the metal foil **24** and the connection strength between the external lead **30** and the metal foil **24** can be prevented from being reduced by forming the wave portion **28** in the area **24u** that is not in the welded portion.

Furthermore, since the split between the metal foil **24** and the glass portion **22** of the sealing portion **20** in use of the lamp occurs from the luminous bulb **10** side of the sealing portion **20**, it is preferable to provide the wave portion **28** on the luminous bulb **10** side rather than on the external lead **30**. For example, based on the longitudinal direction (**Y** direction), a wave crest **24cr** of the wave portion **28** is provided in an area **24w** that is from the midpoint (**24ct**) of the metal foil **24** to the end **12e** of the electrode **12**. The area **24w** includes the midpoint **24ct**. In this embodiment, the wave crest **24cr** extends in the direction of the shorter side of the metal foil **24** (**X** direction), and is formed across the metal foil **24**. It is preferable to form a plurality of wave crests **24cr** in the area **24u** to disperse the internal stresses **40** effectively.

In this embodiment, two wave portions **28** are formed in the metal foil **24** having the corrugated structure. However, forming at least one wave portion **28** can reduce the synthetic stress that causes the metal foil **24** to split the sealing portion **20** over the prior art. Therefore, it is not necessary for the metal foil **24** having the corrugated structure to have a cyclic corrugated structure. However, the entire metal foil **24** can have a cyclic

corrugated structure so that the synthetic stress splitting the sealing portion **20** can be reduced uniformly in the entire portion.

The wave portion **28** has a height (or amplitude) and a radius of curvature that allow the internal stress **40** in the metal foil **24** to be dispersed, and the height (or amplitude) and the radius of curvature of the wave portion **28** can be determined suitably depending on the required conditions. From the constraints of the production process, the maximum height (or amplitude) of the wave portion **28** is defined by the inner diameter of the glass tube **22** portion that becomes the sealing portion of the glass pipe for discharge lamps used in the production process. When the radius of curvature of the wave portion **28** is small rather than large, the internal stresses **40** in the metal foil **24** can be dispersed more satisfactorily. Therefore, it is preferable to form a plurality of wave portions **28** having a relatively small radius of curvature. In this embodiment, the metal foil **24** has a wave portion **28** with a height of about 1 to 2mm and a radius of curvature of about 1 to 4 mm. It is preferable to form a wave portion **28** in a smooth shape rather than a sharp shape to disperse the internal stresses **40** in the metal foil **24** satisfactorily. Even the wave portion (bend portion) **28** is sharp, the internal stresses **40** in the metal foil **24** can be dispersed, compared with the prior art.

Whether or not the wave portion **28** is formed in the metal foil **24** can be determined by comparing the length in the longitudinal direction (the **Y** direction in the drawings) of the metal foil **24** before sealed by the glass portion **22** with the length in the longitudinal direction of the metal foil **24** after the sealing in

view of the thermal expansion coefficient. When the wave portion **28** having a predetermined height (or amplitude) and a predetermined radius of curvature is formed, the length in the longitudinal direction of the metal foil **24** after sealing becomes shorter than that before sealing because of the formation of the wave portion **28**. In the case where measuring and evaluating the height or the radius of curvature of the wave portion **28** are complicated, a change in the length of the metal foil **24** in the longitudinal direction before and after sealing is measured so that the wave portion **28** can be evaluated.

In this embodiment, one sealing portion **20** of the pair sealing portions has the corrugated structure. However, the other sealing portion **20'** can have the corrugated structure as well. It is preferable to provide both of the pair sealing portions with the corrugated structure, because the sealing structure of both of the sealing portions **20** and **20'** can be maintained for a long time. Furthermore, one sealing portion **20** can have the corrugated structure and the other sealing **20'** can have the twist structure of Embodiment **1**. With this design, the sealing structure of both of the sealing portions **20** and **20'** can be maintained for a long time. Furthermore, either the sealing portion **20** or **20'** can have both the corrugated structure and the twist structure.

Next, a method for producing the discharge lamp **200** will be described with reference to Figs. **9A** to **9C**. Figs. **9A** to **9C** are cross-sectional views showing each process in a method for producing the discharge lamp **200**.

First, as shown in Fig. **9A**, the metal foil (Mo foil) **24** having

the electrode **12** and the external lead **30** is inserted in a glass pipe for discharge lamps having a portion for the luminous bulb **10** (luminous bulb portion) and a portion for the glass portion **22** (side tube portion) of the sealing portion (electrode insertion process).

Next, as shown in Fig. **9B**, the pressure in the glass pipe is reduced (e.g., one atmospheric pressure or less), and the glass tube **22** is heated and softened by a burner **50**, so that the glass tube **22** and the metal foil **24** are attached. Thus, the sealing portion **20** is formed (sealing portion formation process).

In the sealing portion formation process, when a force is applied to the direction of arrow 52, a part of the glass tube (glass portion) **22** that has been heated and softened by the burner **50** is deformed. Since the metal foil **24** is softened, this deformation forms the wave portion **28** in the metal foil **24**, as shown in Fig. **9C** (wave portion formation process). The force to the direction of the arrow **52** can be applied directly with an instrument or the like, or by utilizing the difference in the pressure between the inside and the outside of the glass pipe. When the wave portion formation process is repeated a plurality of times, a plurality of wave portions **28** can be formed in the metal foil **24**.

Furthermore, if the sealing portion formation process can be performed satisfactorily, the discharge lamp **200** provided with the metal foil **24** having the corrugated structure can be produced by the following manner. In the electrode insertion process, the metal foil **24** previously provided with the wave portions **28** is

inserted in the glass pipe for discharge lamps, and then the sealing portion forming process is performed. Such a production method is advantageous when a large number of wave portions **28** having a relatively small radius of curvature are formed.

More specifically, the method shown in Fig. **9** can be performed in the manner shown in Figs. **10A** to **10D**. Figs. **10A** to **10D** are cross-sectional views of a process sequence for illustrating a method for producing the discharge lamp **100** of this embodiment.

First, as in the same manner shown in Figs. **5A** and **5B**, as shown in Figs **10A** and **10B**, the electrode assembly is inserted in the side tube portion **22** of the prepared glass pipe, and then the glass pipe is purged with an inert gas with one atmospheric pressure or less. As the metal foil **24** of the electrode assembly, a substantially straight foil is used.

Next, as shown in Fig. **10C**, the side tube portion **22** is heated and melted while rotating the glass pipe, so that the entire metal foil **24** of the electrode assembly is attached to the side tube portion **22** for sealing so as to form the sealing portion **20**.

Thereafter, as shown in Fig. **10D**, first, the sealing portion **20** (glass portion **22**) corresponding to a site to be corrugated of the metal foil **24** is heated and melted. Then, an external force 52 is applied to shrink the glass pipe in the longitudinal direction, so that the wave portion **28** is formed in the metal foil **24**. In other words, the side tube portion **22** is contracted so that the electrode **12** side portion is brought relatively close to the external lead **30** side portion, and thus the wave portion **28** can be formed. The wave portion **28** can be formed by moving the glass pipe in such

a direction that the glass pipe is contracted in both sides, or by moving only one end with the other end being fixed. Furthermore, as the external force **52**, gravity can be utilized.

Thus, the metal foil **24** having the corrugated structure can be produced relatively easily. Therefore, the discharge lamp **200** of this embodiment can be obtained by a known technique. The metal foil **24** having the corrugated structure can be produced in the manner shown in Figs. **11A** to **11D**.

First, in the same manner as shown in Figs. **10A** and **10B**, as shown in Figs. **11A** and **11B**, the electrode assembly is inserted in the side tube portion **22** of the prepared glass pipe, and then the glass pipe is purged with an inert gas with one atmospheric pressure or less.

Next, as shown in Fig. **11C**, the glass pipe is heated and melted from around a boundary portion between the luminous bulb portion **10** and the side tube portion **22** toward the end (upper portion) of the side tube portion **22** to shrink the side tube portion **22** so that a part of the metal foil **24** of the electrode assembly and a part of the side tube portion (glass portion) **22** are attached for sealing.

Then, as shown in Fig. **11D**, when heating reaches the site to be corrugated of the metal foil **24**, both the ends of the glass pipe is contracted in the longitudinal direction, so that the wave portion **28** can be formed in the metal foil **24**. The direction of the heating and melting is not limited to from the boundary portion between the luminous bulb portion **10** and the side tube portion **22** toward the end of the side tube portion **22**, and heating and

melting can be performed from the end of the side tube portion **22** toward the boundary portion between the luminous bulb portion **10** and the side tube portion **22**.

Next, a variation of the metal foil **24** having the corrugated structure will be described with reference to Figs. **12A** and **12B**.

As shown in Fig. **12A**, instead of the wave portion (bend portion) **28** of the metal foil **24** of the discharge lamp **200**, at least one bend portion **29** can be formed on the upper surface **24a** of the metal foil **24**. Also in this discharge lamp **300** provided with the metal foil **24** of the corrugated structure having such a bend portion **29**, the internal stresses **40** in the metal foil **24** can be dispersed. Furthermore, as shown in Fig. **12B**, a plurality of bend portions **29** can be formed in the direction (the **x** direction in Fig. **12B**) perpendicular to the thickness direction of the foil. The discharge lamp **300** can be produced by inserting the metal foil **24** previously provided with the bend portion **29** in the glass pipe for a discharge lamp, and then performing the sealing portion formation process.

As shown in Fig. **13**, the structure in which the cross section of the metal foil **24″** on the shorter side is corrugated is not preferable for the following reason. When the wave crest of the corrugated structure extends along the longitudinal direction (**Y** direction) of the metal foil **24″**, the sealing portion forming process (see Fig. **9B**) cannot virtually be performed. In other words, in the sealing portion formation process, even if the glass portion **22″** is contracted, the recessed area **23″** of the metal foil **24″** cannot be attached to the glass portion **22″**, and gaps between the

metal foil **24″** and the glass portion **22″** are generated. Thus, foil-sealing cannot be achieved. Furthermore, it is virtually impossible from a technical point of view to corrugate the metal foil as shown in Fig. **13** after the sealing portion including the metal foil that is not corrugated but straight is formed earlier. In addition, in the structure shown in Fig. **13**, the portion of the metal foil **24″** that is welded with the electrode rod **16″** of the electrode is corrugated, so that the connection strength between the electrode rod **16″** and the metal foil **24″** can be reduced.

In the discharge lamp of this embodiment, the metal foil **24** has the corrugated structure, so that the directions of the internal stresses **40** of the metal foil **24** in the sealing portion **20** can be dispersed. Therefore, compared with the prior art, the sealing structure of the sealing portion **20** can be maintained for a long time and the lifetime of the lamp can be prolonged.

<u>Embodiment 3</u>

A discharge lamp **400** of Embodiment **3** of the present invention will be described with reference to Figs. **14A** to **14D** and **15A** to **15C**. The discharge lamp **400** of this embodiment is different from the discharge lamp **100** of Embodiment **1** in that the upper surfaces of a pair of metal foils are nonparallel to each other.

Fig. **14A** is a schematic top view of the discharge lamp **400** of this embodiment. Fig. **14B** is a schematic side view of the discharge lamp **400**. Fig. **14C** is a cross-sectional view of the sealing portion **20** taken along line c-c′ of Fig. **14A**. Fig. **14D** is a cross-sectional view of the sealing portion **20′** taken along

line d-d′ of Fig. **14A**.

The discharge lamp **400** of this embodiment includes a luminous bulb **10**, and a pair of sealing portions **20** and **20′** connected to the luminous bulb **10**. The surfaces of a pair of metal foils **24** and **24′** of a pair of sealing portions **20** and **20′** are nonparallel to each other. More specifically, as shown in Figs. **14C** and **14D**, a first direction **x** perpendicular to the thickness direction of the metal foil **24** in one of the sealing portions **20** is different from a second direction **x′** perpendicular to the thickness direction of the metal foil **24′** in the other sealing portion **20′**. In this embodiment, the first direction **x** of the metal foil **24** and the second direction **x′** of the metal foil **24′** are dislocated by 90°.

In the discharge lamp **400**, the first direction **x** of the metal foil **24** and the second direction **x′** of the metal foil **24′** are different from each other, so that as shown in Fig. **15A**, a dislocation of an angle θ occurs between the metal foils **24** and **24′**, based on the end faces of the metal foils. As shown in Fig. **15B**, when the surfaces of the metal foils **24** and **24′** are parallel to each other (angle $\theta = 0°$), the synthetic stress of the internal stress σ of the metal foil **24** and the internal stress σ of the metal foil **24′** is 2σ. On the other hand, when the angle θ is 90°, for example, as shown in Fig. **15C**, the synthetic stress of the internal stresses σ of the metal foil **24** and the metal foil **24′** is σ, which is a half of that when the angle θ is 0°.

Thus, when the first direction **x** of the metal foil **24** and the second direction **x′** of the metal foil **24′** are dislocated, the synthetic stress that causes the pair of the metal foils **24** and

24′ to split the pair of the sealing portions **20** and **20′** can be reduced, compared with when the first direction **x** and the second direction **x′** are the same. As a result, , the sealing structure of the sealing portions **20** and **20′** can be maintained for a long time and the lifetime of the lamp can be prolonged over the prior art.

In order to reduce the synthetic stress (2σ in Fig. **15B**) of the metal foils **24** and **24′** when the first direction **x** of the metal foil **24** agrees with the second direction **x′** of the metal foil **24′** by about 10%, it is preferable that the angle θ is at least 25°. In order to reduce more significantly the synthetic stress of the metal foils **24** and **24′**, it is preferable that the angle θ is at least 30°. In order to reduce the synthetic stress of the metal foils **24** and **24′** by about 15%, it is preferable that the angle θ is at least 45°. As shown in Fig. **15C**, when the angle θ is at least 90°, this is most preferable because the synthetic stress of the metal foils **24** and **24′** can be the smallest (i.e., 50% reduction from 2σ).

The discharge lamp **400** can be produced by, for example, inserting a pair of metal foils **24** and **24′** having electrodes and external leads in a glass pipe for discharge lamps in such a manner that a predetermined angle θ is formed in the electrode insertion process, and then performing the sealing portion formation process.

In this embodiment, the metal foils **24** and **24′** having a rectangular and parallel shape. However, it is possible to form the twist portion **26** or the wave portions (bend portions) **28** and **29** of Embodiments **1** and **2** in at least one of the metal foils **24**

and **24'**. In addition to the effect of this embodiment, the effects of Embodiments **1** and **2** can be obtained by forming the twist portion **26** or the wave portion **28** or the like in one or both of the metal foils **24** and **24'** in this embodiment. When the twist portion or the wave portion is formed, for example, the angle θ can be set based on the portions on the luminous bulb **10** side of the metal foil **24**.

In the discharge lamp of this embodiment, the first direction **x** of the metal foil **24** and the second direction **x'** of the metal foil **24'** are dislocated by the angle θ, so that the synthetic stress that causes the pair of metal foils to split the pair of sealing portions can be reduced. Therefore, the sealing structure of the pair of sealing portions can be maintained for a long time and the lifetime of the lamp can be prolonged.

Embodiment **4**

A discharge lamp **500** of Embodiment **4** of the present invention will be described with reference to Figs. **16A** and **16B**. Fig. **16A** is a schematic top view of a part of the discharge lamp **500** of this embodiment. Fig. **16B** is a cross-sectional view of the sealing portion **20** taken along line b-b' of Fig. **16A**.

In the discharge lamp **500** of this embodiment, at least one of a pair of metal foils is as follows. The area of the metal foil (Mo foil) **24** projected from the luminous bulb **10** side to the external lead **30** side is larger than the area of the end face **24c** of the metal foil **24**. In the discharge lamp **500**, the twist portion **26** of Embodiment **1** is formed in the metal foil **24** to make the projected

area of the metal foil **24** larger than that of the end face **24c**. More specifically, as shown by a dotted line in Fig. **16B**, each of the upper surface and the lower surface of the metal foil **24** forms a semicircle locus when viewed from the luminous bulb **10** side. Thus, the projected area of the metal foil **24** when the metal foil **24** is projected from the luminous bulb **10** side to the external lead **30** side is larger than the area of the end face **24c** of the metal foil **24**. In this embodiment, the metal foil **24** is twisted by 180°, but can be twisted by, for example, 90°. When the metal foil **24** is twisted by 90°, the projected shape of each of the upper surface and the lower surface of the metal foil **24** is a quarter of a circle. Furthermore, the projected area of the metal foil **24** can be larger than the area of the end face **24c** by forming the wave portion of Embodiment **2**.

When the discharge lamp is operated, a large amount of energy (e.g., about 150W) is introduced in a small space of the luminous bulb **10**, and therefore the energy in the luminous bulb **10** moves in the glass portion **22** of the sealing portion **20** in the direction of arrow **36** in a manner similar to in a optical fiber (optical fiber-like effect). The energy moving in the glass portion **22** by the optical fiber-like effect heats a welded portion **32** joining the metal foil **24** and the external lead **30**.

In the discharge lamp **500**, the projected area of the metal foil **24** is larger than the area of the end face **24c** of the metal foil **24**, and therefore the upper surface or the lower surface of the metal foil **24** can receive the energy moving from the luminous bulb **10** to the external lead **30** by the optical fiber-like effect.

Therefore, the energy by the optical fiber-like effect that reaches the welded portion **32** joining the metal foil **24** and the external lead **30** can be reduced from the prior art, so that the temperature increase in the welded portion **32** can be reduced. Molybdenum constituting the metal foil **24** and the external lead **30** is oxidized at 350°C or more, even if sealing is ensured with the glass portion **22**. However, the oxidation of the molybdenum can be prevented by suppressing the temperature increase of the welded portion **32**, and thus the reliability of the discharge lamp can be improved. In order to suppress the temperature increase in the welded portion **32**, it is preferable to form the twist portion **26** (or the bend portion) on the luminous bulb **10** side rather than in the center of the metal foil **24**.

Embodiment 5

A discharge lamp **600** of Embodiment **5** of the present invention will be described with reference to Fig. **17**. Fig. **17** is a schematic top view of a part of the discharge lamp **600** of this embodiment.

In at least one of a pair of sealing portions **20** of the discharge lamp **600** of this embodiment, the external lead **30** and the metal foil (Mo foil) **24** constituting molybdenum are integrally formed. In the discharge lamp **600**, the external lead **30** and the Mo foil **24** are integrally formed in the sealing portion **20**, so that the welded portion that might be present in the prior art is not present in the junction **32** between the Mo foil **24** and the external lead **30**. For this reason, the contact resistance between the external lead **30** and the Mo foil **24** can be reduced significantly, and a

local temperature increase in the junction **32** can be suppressed. Therefore, a larger amount of current can flow than in the prior part while preventing oxidization of the Mo foil **24**, and thus higher intensity can be achieved. Furthermore, by suppressing the local temperature increase in the junction **32**, the starting point of cracks can be prevented from occurring in the glass portion **22** in the periphery in the junction **32**, so that the strength of the sealing portion **20** can be maintained. Furthermore, the junction **32** can have a smooth shape, so that this structure hardly allow a gap to be formed between the junction **32** and the glass portion **22**. As a result, the strength of the sealing portion **20** can be improved.

The Mo foil **24** integrally formed with the external lead **30** can be produced by a known technique. For example, a round rod or a square rod (Mo rod) made of molybdenum having a predetermined length is prepared, and then a predetermined portion of the Mo rod is passed through a pair of rollers to be extended to form the Mo foil **24**. The unextended portion can be used as the external lead **30**. Instead of rollers, dies can be used. The Mo foil **24** integrally formed with the external lead **30** can be produced by embossing.

For the purpose of reducing the contact resistance between the external lead **30** and the Mo foil **24**, as shown in Fig. **18**, a discharge lamp **700** can have the following structure. Instead of the Mo foil **24** integrally formed with the external lead **30**, the Mo foil **24** of the discharge lamp **700** has a junction **32** obtained by plane-welding the external lead **30** and the Mo foil **24**. As in

the discharge lamp **700**, in the case where the end of the external lead **30** is planed and welded to the Mo foil **24**, face contact can be achieved in contrast to substantially point contact in the prior art. Therefore, it is possible to reduce the contact resistance between the external lead **30** and the Mo foil **24**. Furthermore, in the discharge lamp **700**, the contact area of the junction **32** can be larger than that in the prior art, so that point welding can be performed in an increased number of times, and therefore this is preferable in view of the production process. In addition, the shape of the junction **32** can be smooth.

Embodiment 6

A discharge lamp **800** of Embodiment **6** of the present invention will be described with reference to Fig. **19**. Fig. **19** is a schematic top view of a part of the discharge lamp **800** of this embodiment.

The discharge lamp **800** of this embodiment has a molybdenum rod (Mo rod) **17** extending from the Mo foil **24** to the luminous bulb **10** and connected to the electrode (W electrode) **12** by welding. The end face of the edge of the Mo rod **17** is joined to one end face of an electrode rod **16** of the W electrode **12**. The Mo rod **17** can be joined to the electrode rod **16** by, for example, laser welding, or may be joined by electric welding.

When the Mo rod **17** extending from the Mo foil **24** is connected to the W electrode **12**, the connection portion **17a** can be more smooth than in direct connection of the Mo foil **24** and the W electrode **12**. Therefore, this makes it difficult for cracks to occur in the glass portion **22** in the periphery of the connection portion

17a between the Mo foil **24** and the electrode **12**, so that the strength of the discharge lamp can be improved. When at least one of the pair of the Mo foils **24** has the Mo rod **17**, the strength of the discharge lamp can be improved over the prior art. However, it is more preferable that both of the Mo foils **24** have the rods **17**.

In this embodiment, the Mo foil **24** is plane-welded to the external lead **30**, but it is possible to use the Mo foil **24** integrally formed with the external lead **30**. More specifically, it is form integrally the Mo foil **24**, the Mo rod **17** extending from the Mo foil **24**, and the external lead 30. Furthermore, the external lead **30** can be simply welded to the Mo foil **24** having the Mo rod **17**.

Embodiment 7

The discharge lamps of Embodiments **1** to **6** can be formed into lamp units in combination with reflecting mirrors. Fig. **20** is a schematic cross-sectional view of a lamp unit **900** including the discharge lamp **100** of Embodiment **1**.

The lamp unit **900** includes the discharge lamp **100** including a substantially spherical luminous portion **10** and a pair of sealing portions **20** and a reflecting mirror **60** for reflecting light emitted from the discharge lamp **100**. The discharge lamp **100** is only illustrative, and any one of the discharge lamps of the above embodiments can be used. The lamp unit **900** may further include a lamp house holding the reflecting mirror **60**.

The reflecting mirror **60** is designed to reflect the radiated light from the discharge lamp **100** so that the light becomes, for example, a parallel luminous flux, a condensed luminous flux

converged on a predetermined small area, or a divergent luminous flux equal to that emitted from a predetermined small area. As the reflecting mirror **60**, a parabolic reflector or an ellipsoidal mirror can be used, for example.

In this embodiment, a lamp base **55** is attached to one of the sealing portion **20** of the discharge lamp **100**, and the external lead extending from the sealing portion **20** and the lamp base are electrically connected. The sealing portion **20** attached with the lamp base **55** is adhered to the reflecting mirror **60**, for example, with an inorganic adhesive (e.g., cement) so that they are integrated. A lead wire **65** is electrically connected to the external lead **30** of the sealing portion **20** positioned on the front opening side. The lead wire **65** extends from the external lead **30** to the outside of the reflecting mirror **60** through an opening for a lead wire **65** of the reflecting mirror **60**. For example, a front glass can be attached to the front opening of the reflecting mirror **60**.

Such a lamp unit can be attached to an image projection apparatus such as a projector employing liquid crystal or DMD, and is used as the light source for the image projection apparatus. The discharge lamp and the lamp unit of the above embodiments can be used, not only as the light source for image projection apparatuses, but also as a light source for ultraviolet steppers, or a light source for an athletic meeting stadium, a light source for headlights of automobiles or the like.

<u>Other embodiments</u>

In the above embodiments, mercury lamps employing mercury

as the luminous material have been described as an example of the discharge lamp of the present invention. However, the present invention can apply to any discharge lamps in which the airtightness of the luminous bulb is maintained by the sealing portion (seal portion). For example, the present invention can apply to discharge lamp enclosing a metal halide such as a metal halide lamp.

In the above embodiments, the mercury vapor pressure is about 20MPa (in the case of so-called ultra high pressure mercury lamps). However, the present invention can apply to high-pressure mercury lamps in which the mercury vapor pressure is about 1 MPa, or low-pressure mercury lamps in which the mercury vapor pressure is about 1 kPa. Furthermore, the gap (arc length) between the pair of electrodes **12** and **12'** can be short, or can be longer than that. The discharge lamps of the above embodiments can be used by any lighting method, either alternating current lighting or direct current lighting.

The structures of the above embodiments can be mutually used. For example, it is preferable to combine any one of the structures of Embodiments **1** to **4** with either one of structures of Embodiments **5** and **6** for improvement of the lifetime of the discharge lamp.

The invention may be embodied in other forms without departing from the spirit or essential characteristics thereof. The embodiments disclosed in this application are to be considered in all respects as illustrative and not limiting. The scope of the invention is indicated by the appended claims rather than by the foregoing description, and all changes which come within the

meaning and range of equivalency of the claims are intended to be embraced therein.